Jet Propulsion Laboratory
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Supersonic Retro-Propulsion for Future High-Mass Robotic Mars Lander Missions

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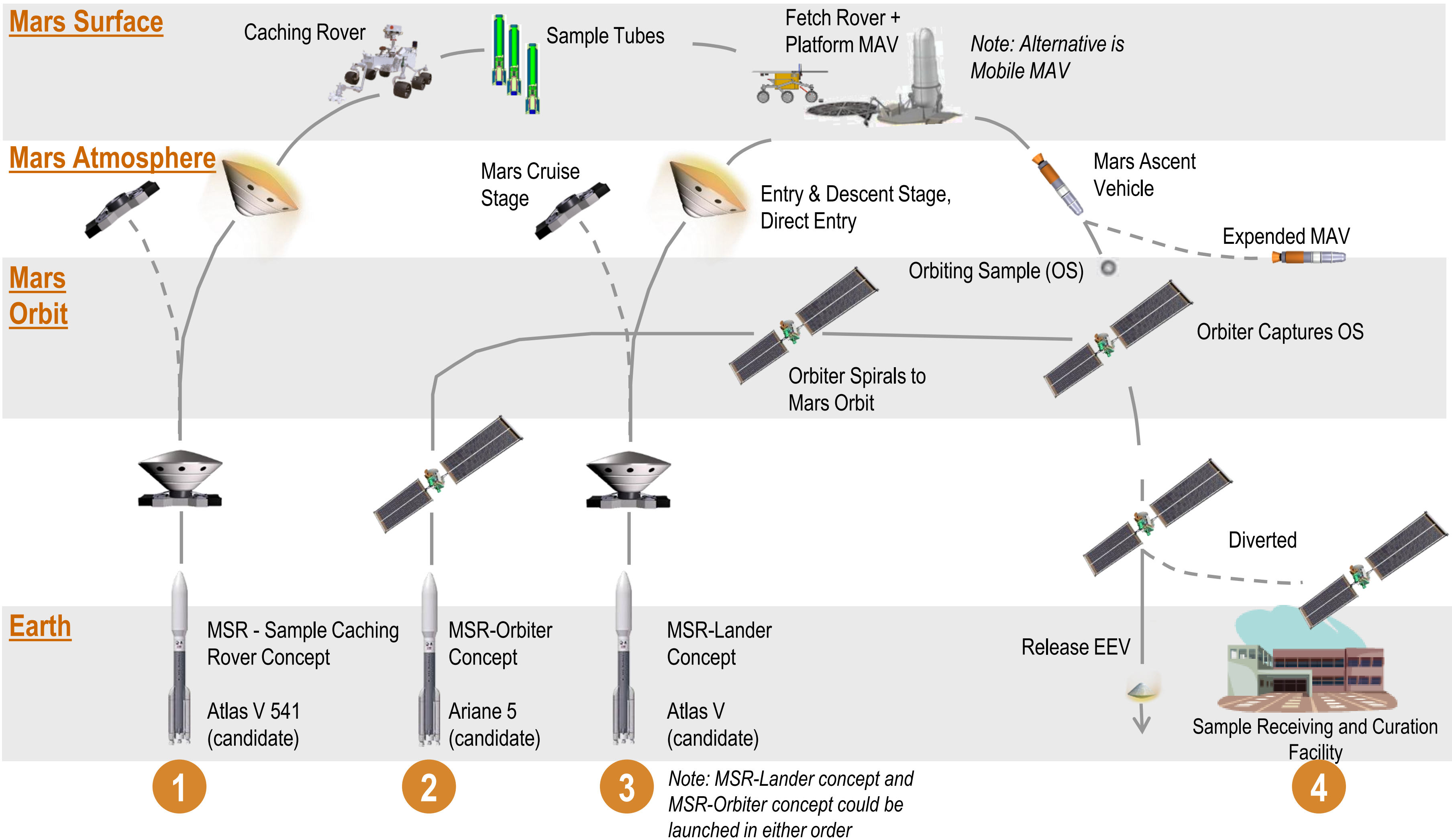
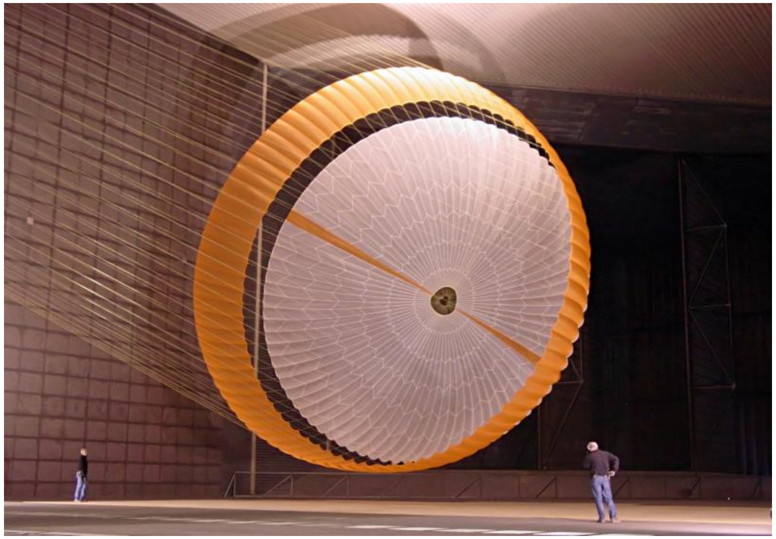
This work includes contributions from a number of individuals at JPL, including: Joel Benito, Rob Grover, Emily Howard, Ashley Karp, Eddie Lau, Rob Manning, Barry Nakazono, Connor Noyes, Hoppy Price, Dan Scharf, Robert Shotwell, Evgeniy Sklyanskiy, Christine Szalai, and David Vaughan

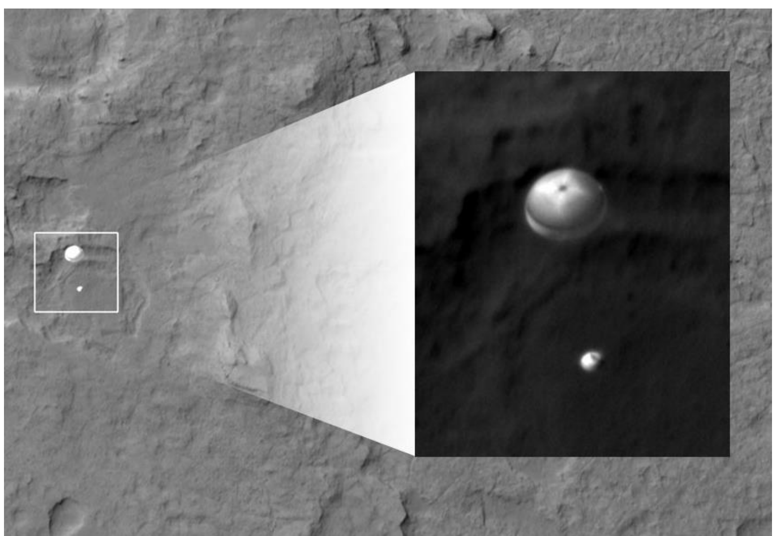
Potential Mars Sample Return – Notional Architecture



Pre-Decisional Information -- For Planning and Discussion Purposes Only

Supersonic Deceleration for Mars





- MSL used a supersonic parachute to land ~1 t on Mars
  - 21.35 m diameter
  - Leveraged Viking and heritage test data

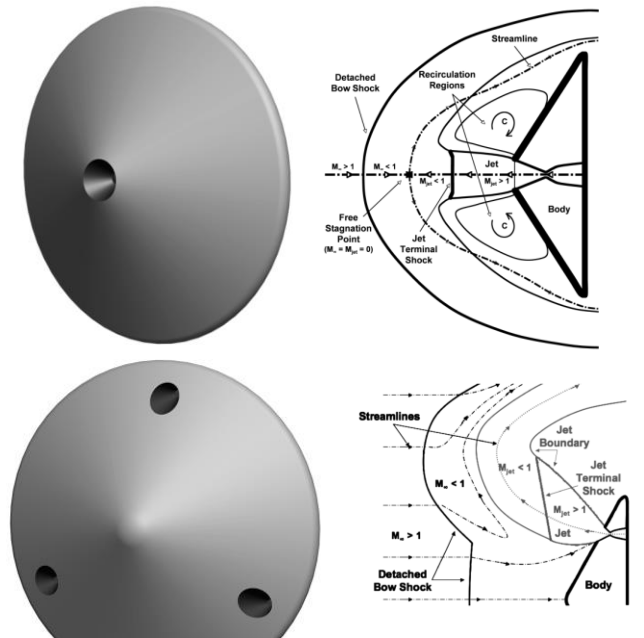
Future >1 t payloads to higher landing elevations will require larger supersonic chutes and new flight testing/validation program

or

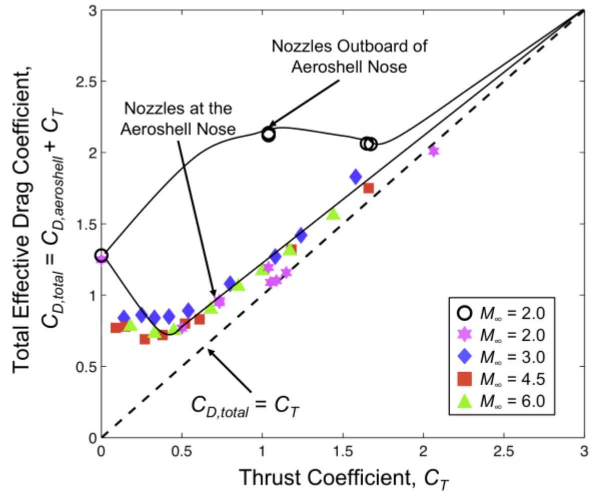
Incorporate other technologies to enable heavier payloads to Mars

Supersonic Retro-Propulsion

- SRP is the use of engine(s) firing in the velocity vector direction during the supersonic phase of entry
  - Provides an alternative to supersonic parachutes to decelerate the entry vehicle



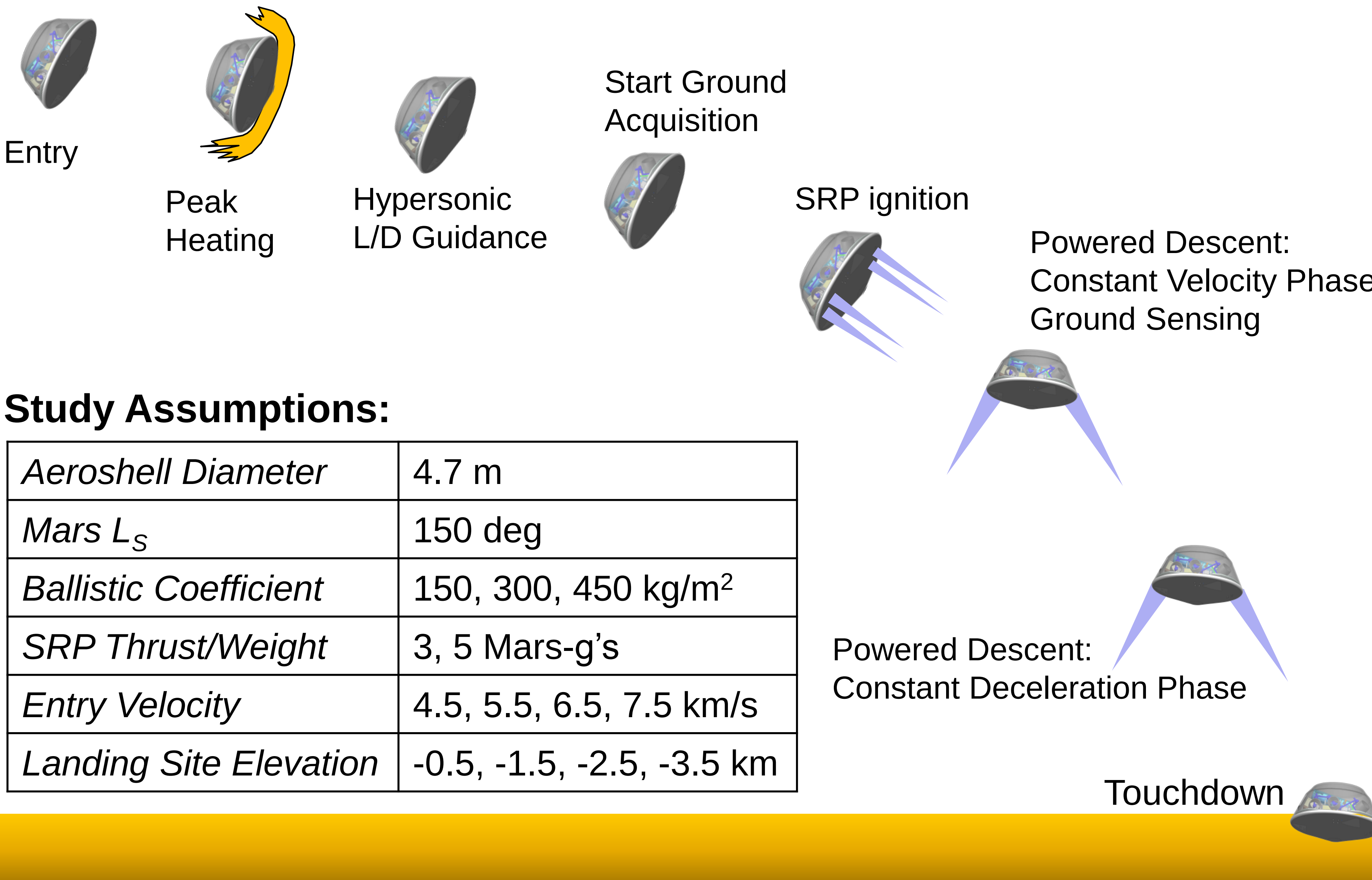
Korzun, A., et al, "Survey of Supersonic Retropropulsion Technology for Mars Entry, Descent, and Landing," J. Spacecraft and Rockets, Vol. 46, No. 5, pp. 929-937, 2009.



Edquist, K., et al, "Development of Supersonic Retro-Propulsion for Future Mars Entry, Descent, and Landing Systems," AIAA Paper 2010-5046, 2010.

http://www.spacex.com

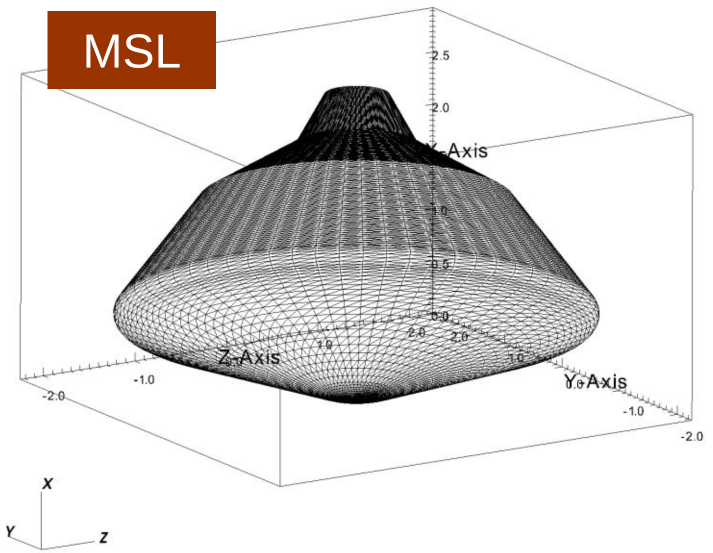
Conceptual SRP Entry and Descent Concept

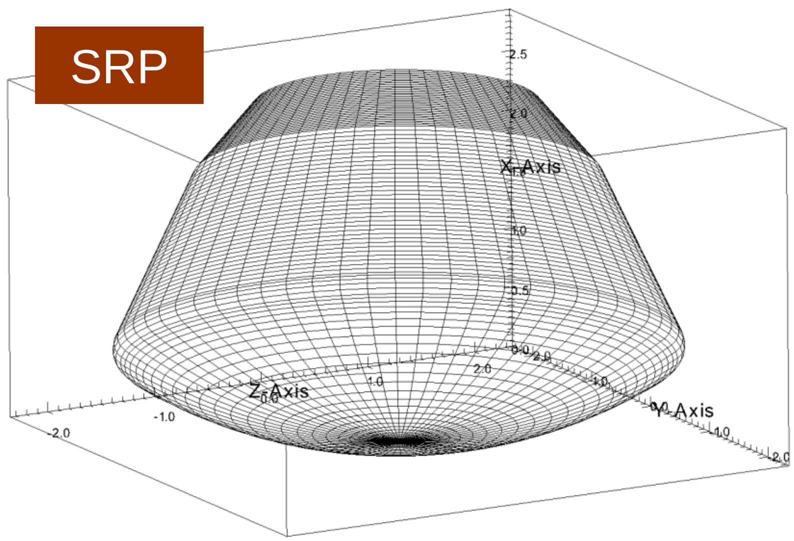


Study Assumptions:

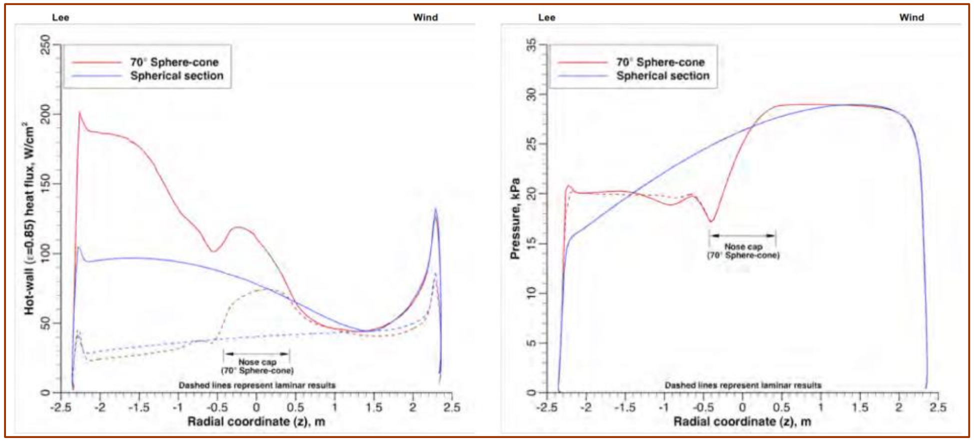
Aeroshell Diameter	4.7 m
Mars L_S	150 deg
Ballistic Coefficient	150, 300, 450 kg/m^2
SRP Thrust/Weight	3, 5 Mars-g's
Entry Velocity	4.5, 5.5, 6.5, 7.5 km/s
Landing Site Elevation	-0.5, -1.5, -2.5, -3.5 km

Conceptual SRP MSR Lander – Aeroshell





- Spherical Heatshield
  - 4.7 m diameter
    - Max that can fit 5 m diameter launch fairing
  - Spherical provides potential heating/packaging benefits vs. sphere-cone
- Backshell
  - Steeper angles to increase packaging volume



Prabhu, D., and Saunders, D., "On Heatshield Shapes for Mars Entry Capsules," AIAA Paper 2012-4297, 2012.

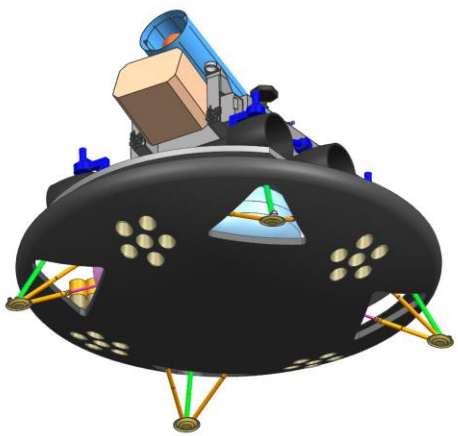
Conceptual SRP MSR Lander – Propulsion

MSL Mars Landing Engine example (mono-propellant, 3300 N thrust)
Note SRP requires 3-4x thrust levels vs. MSL

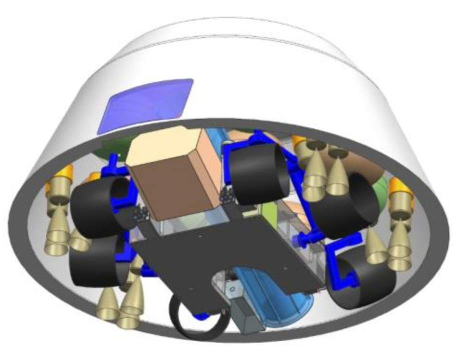
- NTO/MMH bi-propellant
  - Thrust: 8000 N (BC300 cases) or 12,000 N (BC450 cases)
  - 12 engines total (T/W=3 cases) or 20 engines (T/W=5 cases)
  - Area ratio 24:1
    - Driven by aeroshell accommodation constraints
    - Reduces *Isp* of engines
- Electrically driven pumps provide:
  - Increased chamber pressure
  - Increased *Isp*
  - Decreases in thruster dimensions (volume)
  - Minimum thruster and prop tank mass
  - Throttleability (estimated to ~65% thrust)
- Drawback has been battery capacity
  - Battery capacity (Li-ion) is now competitive
  - Current assumption 150 W-hr/kg, projected 300-400 W-hr/kg

Conceptual SRP MSR Lander – Configuration

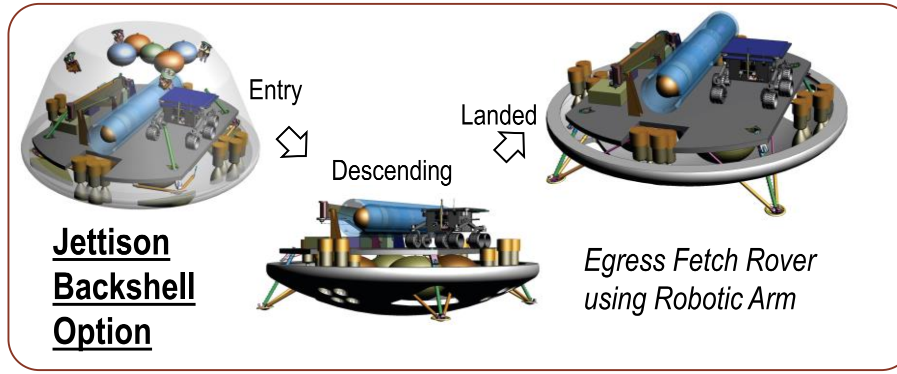
Landed SRP Configuration



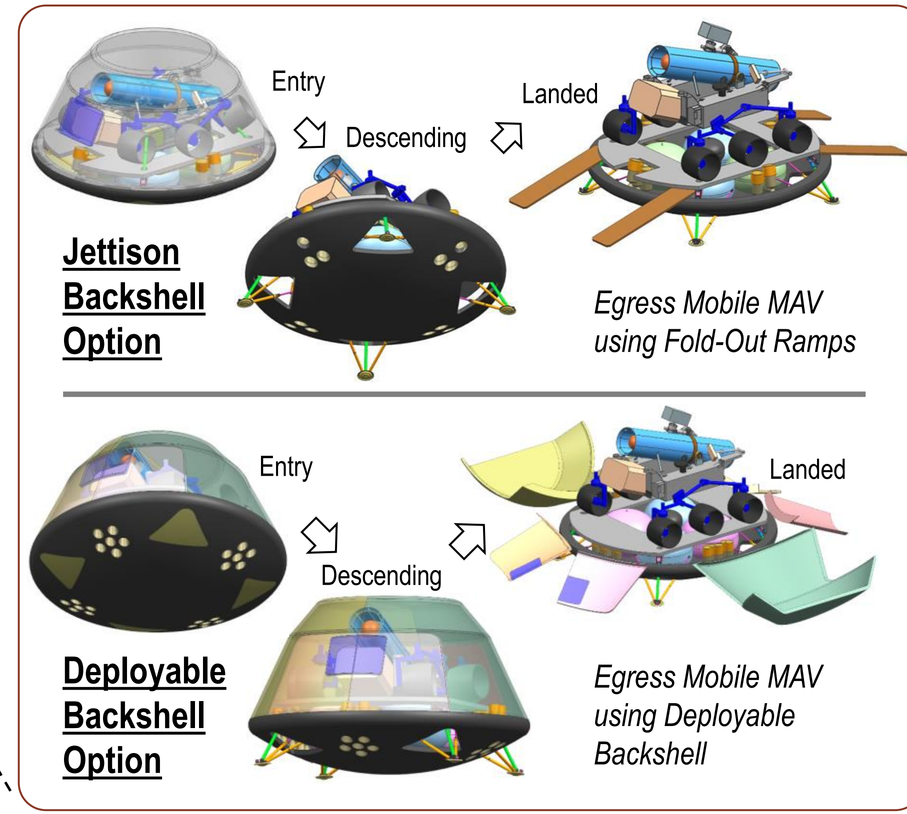
Skycrane SRP Configuration



FETCH ROVER CONCEPT



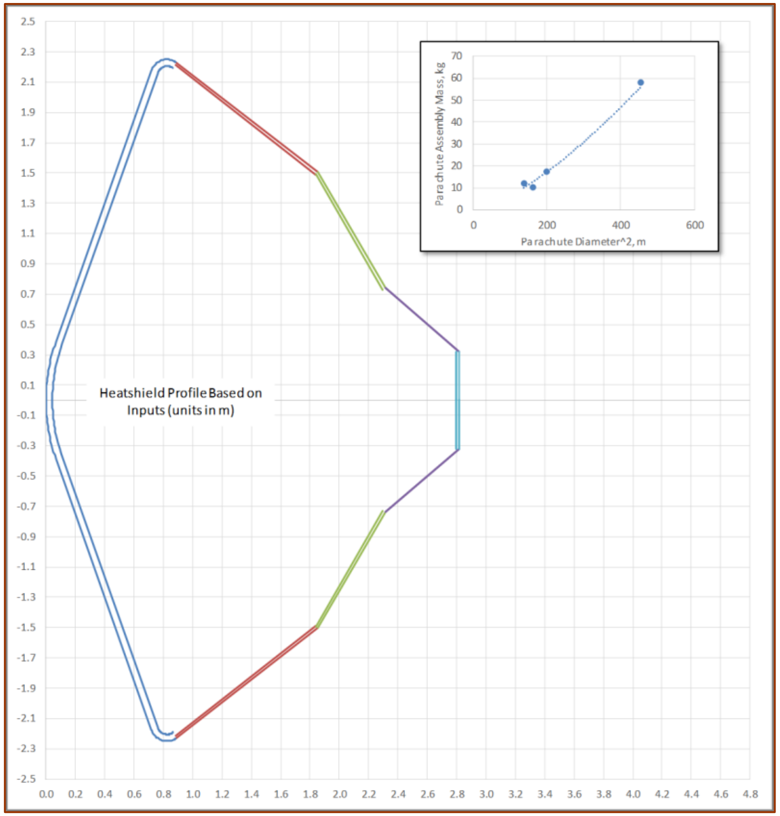
MOBILE MAV CONCEPT



Conceptual SRP MSR Lander – Trajectory Modeling

- Objective
  - Minimize Propellant Mass Fraction (PMF)
    - PMF = (propellant mass) / (wet mass at ignition)
- Key Inputs
  - Entry velocity, entry flight path angle (FPA), bank profile, SRP ignition time, thrust profile
- End State
  - 0.75 m/s descent rate, -90 deg. FPA, propellant remaining for 20 s powered hover

Conceptual SRP MSR Lander – Mass Sizing

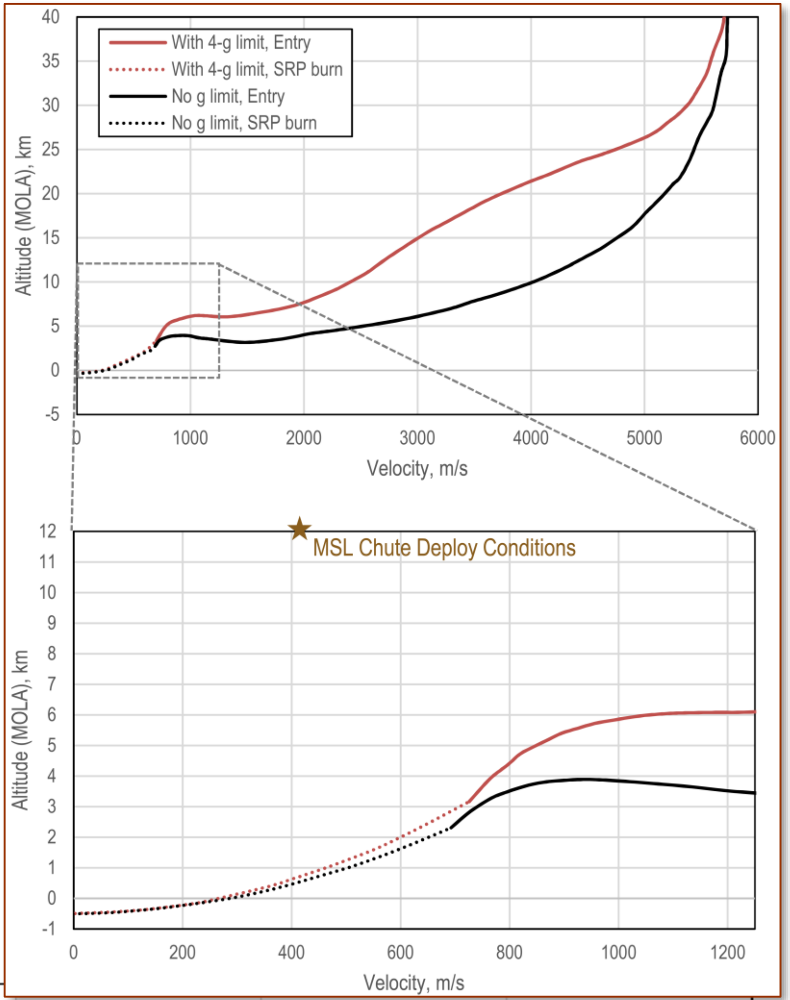


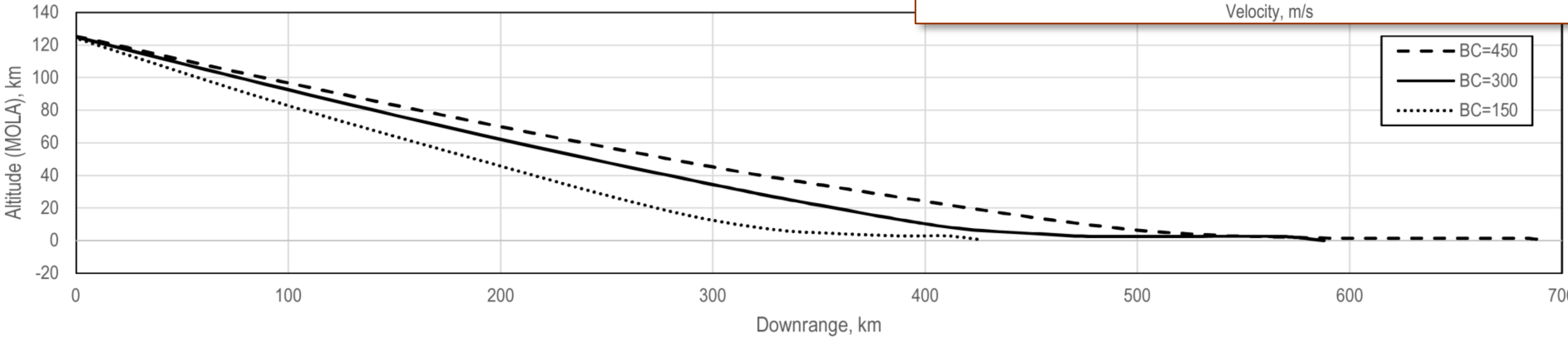
Lobbia, M., "Sizing Methods for Advanced Mars Entry Descent and Landing Systems," 13th International Planetary Probe Workshop, 2016.

- Moderate-fidelity sizing model tailored for SRP configurations
  - Physics-based and historical sizing relationships (MSL, Phoenix, MER, Pathfinder)
  - TPS sizing based on mass fraction correlation to heat load
- Outputs
  - Useful Landed Mass
  - Subsystem and component mass breakdowns

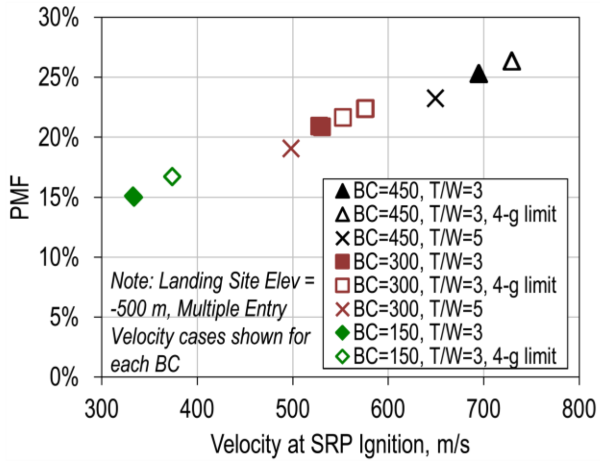
Results – Conceptual SRP Trajectories

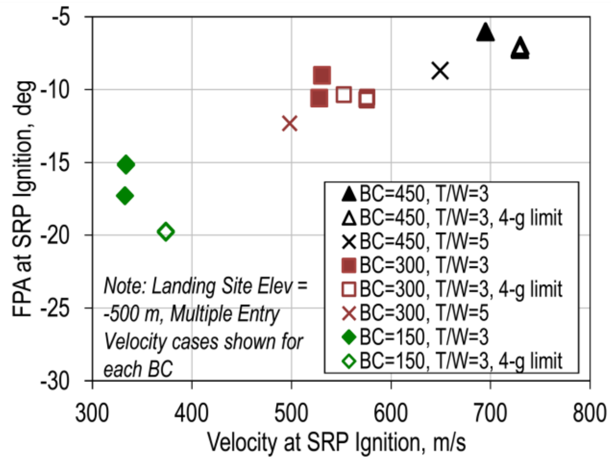
- Larger ballistic coefficient SRP trajectories more shallow and further downrange
- SRP leads to much lower/faster ignition points vs. supersonic chute deploy
- Application of 4-g constraint demonstrates SRP for human precursor missions

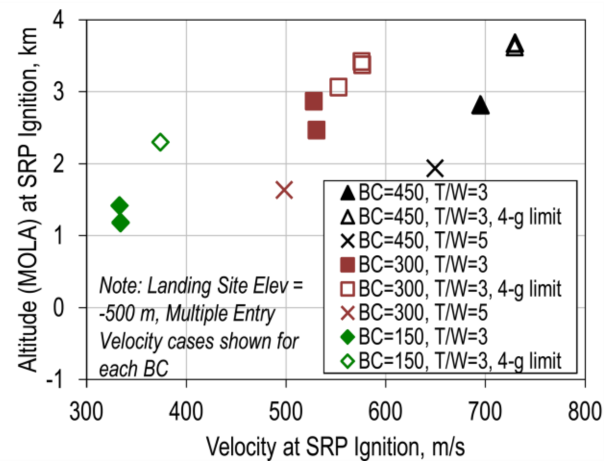


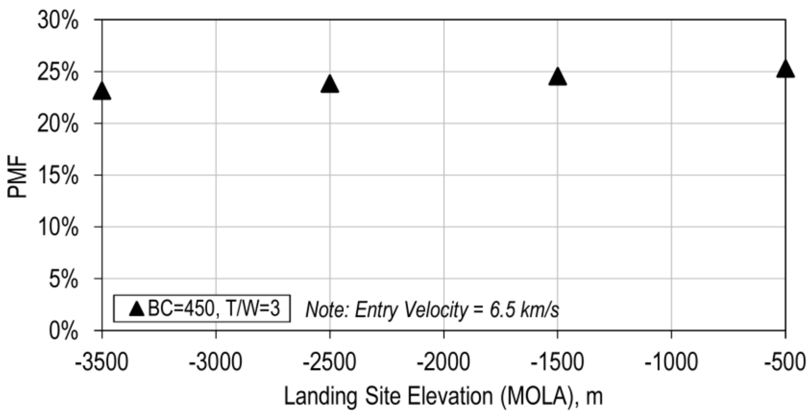


Results – Propellant Mass Fraction Sensitivities





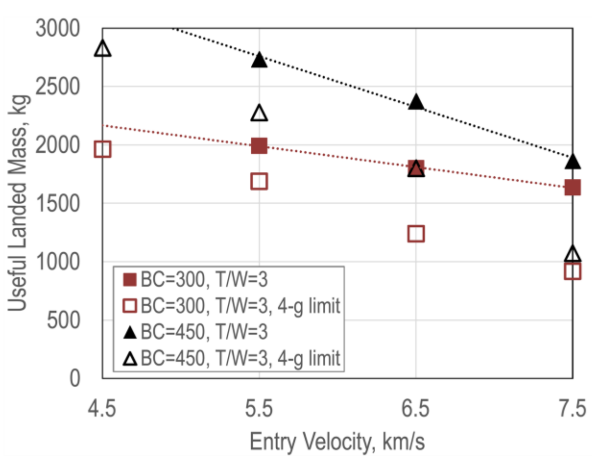


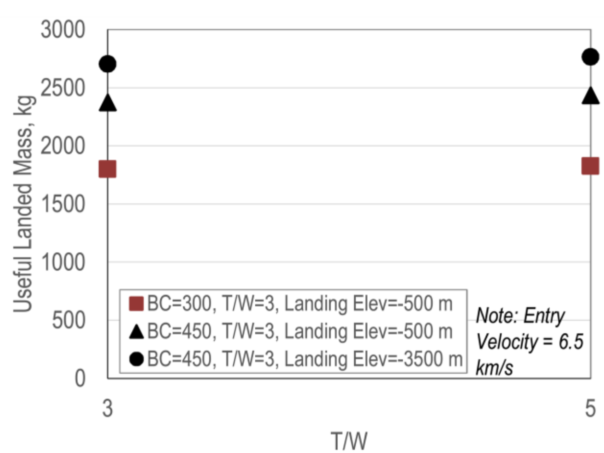


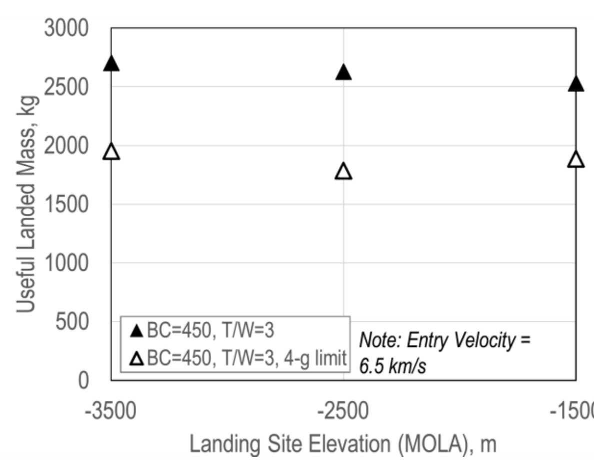
- 4-g deceleration constraint leads to slight increase in PMF
- PMF relatively insensitive to landing site elevation and entry velocity
- Higher *T/W* cases have lower PMF and ignite at lower altitudes/velocities

Results – Mass Sizing

- Useful landed mass sensitivity
  - Small change with respect to T/W and landing site elevation
  - Decreases with higher entry velocities
    - Due to TPS sizing based on heat load
- 4-g deceleration constraint also reduces useful landed mass due to higher heat loads and TPS mass

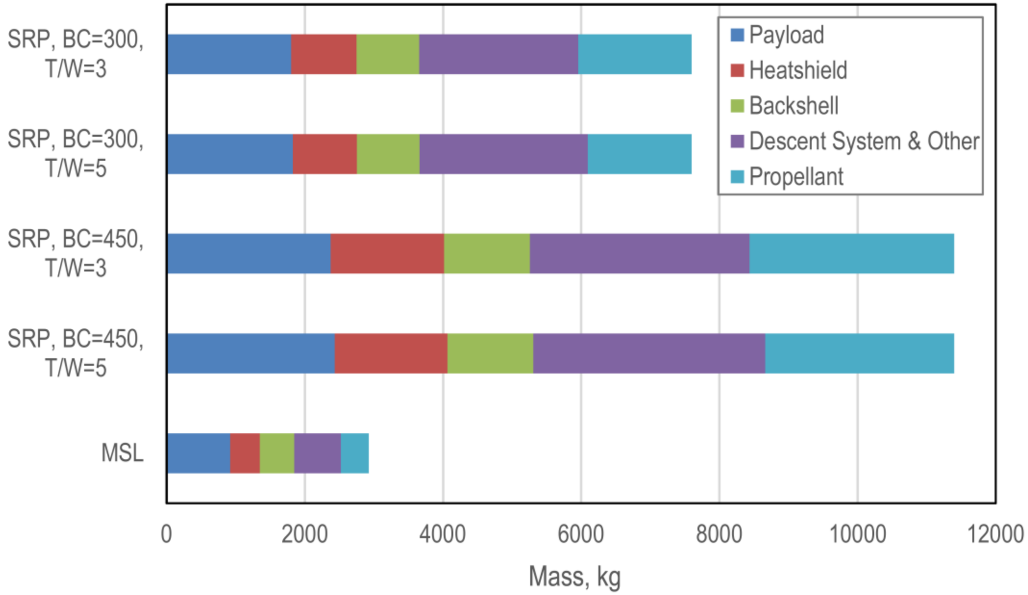






Conclusions and Future Work

- High ballistic coefficient SRP is an enabling technology for increasing useful landed mass to Mars surface
  - Eliminates need for large supersonic chutes
  - Reduces sensitivity to some landing requirements (elevation, entry velocity)



Examples show potential for 300 and 450 kg/m^2 ballistic coefficient SRP designs to land >2x MSL payload to Mars with only a 5% increase in heatshield diameter

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